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Biomass and Residue Cover Relationships of Fresh and Decomposing Small Grain Residue

J. L. Steiner,* H. H. Schomberg, P. W. Unger, and J. Cresap

ABSTRACT

Maintaining residue cover provides diverse conservation benefits. Exponential relationships have been developed to estimate cover from biomass of randomly distributed, flat residues, but a large portion of crop biomass remains standing after harvest. Our objective was to determine how relationships between biomass and soil cover change in no-tillage small grain fields as residues decompose and shift from standing to flat. Winter and spring wheat (*Triticum aestivum* L.), winter barley (*Hordeum vulgare* L.), and spring oat (*Avena sativa* L.) were grown at Bushland, TX, on Pullman clay loam (fine, mixed thermic Torrertic Paleustoll) in 12 field plots in three randomized complete blocks. For each crop, differential seeding rate, fertilization, and irrigation produced a range of biomass. During decomposition, differential irrigation increased environmental variability (13, 5, and 0 applications to sub-sub-plots). Ash-free residue biomass was measured seven times in 14 mo, after taking photographs to determine soil cover of 1-m^2 sites. For crop-date combinations, coefficients were determined from total (k_t, m^2 g^{-1}) or flat (k_f, m^2 g^{-1}) biomass. Regression indicated k_t increased with time ($P < 0.0001$ for all crops, except spring wheat with $P < 0.0041$). Across crops, the relationship $k_t = 0.0037 + 0.000047 \cdot \mathrm{DAH}$ ($r^2 = 0.54$, $P < 0.0001$) indicated that decomposition affects cover provided by total biomass. Across crops, the weak relationship $k_f = 0.0136 + 0.000023 \cdot \mathrm{DAH}$ ($r^2 = 0.17$, $P < 0.016$) indicated that cover could be estimated from flat biomass with $k_f \approx 0.0175$ for extended periods. These findings can improve estimation of residue cover for no-tillage fields and indicate that residue orientation should be considered in biomass-to-cover relationships.

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Conservation tillage systems are adopted for a wide variety of reasons, including decreased production costs, decreased labor, and resource conservation. Many natural resource conservation benefits are attained by retaining increased crop residue cover over longer periods of time, including increased infiltration, reduced evaporation, and reduced soil erosion in the short term as well as long-term enhancements in soil organic matter and structure (Steiner, 1994).

Maintaining surface residue cover is often recommended to reduce erosion by water and wind. Residues contribute to erosion control both through sheltering the soil with a nonerodible material (cover) or through changing the surface conformation in ways that change the flow of water and wind across the surface (roughness or resistence). Both aspects are important for both wind and water erosion. The fraction of soil covered by crop residue also influences raindrop impact on soil surface properties (aggregation, crusting, etc.) and on the surface aerodynamic properties (Hagen, 1991). The processes of wind and water erosion are interactive—changes in soil or residue surface properties by either wind or water impacts the erodibility of that surface when exposed to future wind or water erosive forces.

In spite of this complexity, where erosion is primarily by water, the required amount of residue has been based on surface cover (with 30% cover required after planting

Abbreviations: DAH, days after harvest; k_f, flat biomass cover coefficient (m^2 g^{-1}); k_t, total biomass cover coefficient (m^2 g^{-1}); M, residue biomass (g m^{-2}).

the subsequent crop) with less focus on conformational aspects. Wind erosion control programs have also often been based on cover, in spite of the fact that the height and number of standing residue elements are also related strongly to the degree of erosion control achieved (Bilbro and Fryrear, 1994; Nielsen and Aiken, 1998). Standing residues contribute less to cover than flat residues, but persist longer because of slower decomposition rates. Additionally, standing stems probably provide more soil protection than a vertical-view cover estimate indicates, because erosive rains often come in storms where rain is blown by strong winds at low angles to the surface. Standing stems intercept blown rain along the length of the stem, reducing the direct impact of raindrops on soil particles (Morrison et al., 1984).

The relationship between residue biomass and residue cover has been described for many crops and exhibits an exponential relationship, assuming randomly distributed, flat residue elements (Gregory, 1982). Additionally, Gregory (1982) showed that the exponential cover coefficient was shown to be related to the area/biomass ratio of individual residue elements (Greb, 1967) that provide the cover. The biomass-to-cover relationship plateaus at high biomass levels, so considerable biomass decomposition may occur before cover decreases. If crop biomass is low, decomposition will be associated with loss of cover. For leafy residues, there may be loss in soil cover with relatively little change in biomass, because leaf material decomposes rapidly and provides significant cover per unit biomass compared with stem material (Gregory, 1982). Erosion processes can also redistribute residue elements, particularly the light material, and decrease their effectiveness in providing cover. Leaves contribute relatively less biomass than stems. Soluble carbohydrates, which comprise as much as 20% of the biomass at harvest, can leach into the soil with little change in cover. Decomposition may occur in the stem's interior, leaving the stem exterior (and soil cover) relatively intact. For a given species, a similar percent cover can be achieved in field environments with a wide range of residue biomass and distribution. The change of cover over time depends on the initial amount and distribution of residue. McCool et al. (1995) analyzed relationships between reduction in cover and reduction in surface biomass associated with tillage operations, but no similar analysis is available for changes in cover with reduction in surface biomass by decomposition.

Estimating soil cover from biomass remains useful, despite the difficulties described above, because field measurements are also problematic. Recommended line-intercept measurement methods are often subjective and produce highly variable results (Morrison et al., 1995). Available remote sensing techniques that are economically feasible cannot reliably separate background soil from residue cover across the wide range of conditions found in agricultural fields (Daughtry et al., 1996).

Erosion models include residue decomposition submodels (Stott et al., 1995; Steiner et al., 1995) because of the extreme sensitivity of erosion prediction to surface residues. Residue decomposition models usually predict biomass loss (Stroo et al., 1989; Ghidey et al., 1985; Douglas and Rickman, 1992), and sometimes maintain separate pools of residue such as standing and surface biomass (Stott et al., 1995; Steiner et al., 1995). In semiarid regions, residue may remain standing for over a year following harvest (Tanaka, 1986; Steiner et al., 1994).

Different researchers have had different results when trying to compare the relationship among residue biomass and surface cover for different small grain crops. Greb (1967) analyzed several small grains and indicated the highest coefficient for spring barley and lower coefficients for winter wheat and oat. McCool et al. (1990) found the highest coefficient for spring wheat, a lower coefficient for winter barley, and three different lower coefficients for three winter wheat varieties. Data of Sloneker and Moldenhauer (1977) indicate exceptionally high cover per unit biomass of oat for field residue samples collected over several months as they decomposed and were degraded by tillage operations.

To estimate adequately soil cover from residue biomass, better information is needed about cover provided in no-tillage fields where a portion of the biomass may be near vertical. Our objective was to determine how residue biomass and surface cover relationships change in no-tillage small grain fields as residues decompose and shift from standing to flat orientation.

MATERIALS AND METHODS

Field Experiments

Residue biomass and cover over time were monitored under no-tillage management for 'TAM-107'[1] winter wheat, 'Oslo' spring wheat, 'Post' winter barley, and 'Lew' spring oat at the USDA, Agricultural Research Service, Conservation and Production Research Laboratory, Bushland, TX (35° N lat., 102° W long., 1170 m elev., 476 mm mean annual precipitation; 13.3°C mean annual temperature). The climate is continental, with precipitation falling predominately in the summer months and potential evaporation more than double precipitation in all months. Crops were grown on a Pullman clay loam (fine, mixed thermic Torrertic Paleustoll) in 0.25 m north-south rows. Twelve main plots (12 by 70 m) were arranged in three randomized complete blocks of the four crop treatments. High, medium, and low initial biomass subplots were established for each crop by differentially managing seeding rate, fertilization, and growing season irrigation (Steiner et al., 1994, 1999). Harvest height was varied in each plot to leave as much residue standing as possible, while still removing the lowest heads. The highest biomass plots tended to have the highest combine header height, but height of standing stubble was not measured by plot. Following harvest, each crop-density subplot was divided into thirds for decomposition-period treatments consisting of nonirrigated, full irrigation, and alternate-date irrigation, randomly assigned to sub-sub-plots. Full-irrigation plots were irrigated to maintain a moist surface (as often as weekly) as described in Steiner et al. (1999) and alternate-date irrigation was on roughly every other full-irrigation date (in some cases rainfall following the full-irrigation

[1] Reference to a trade or company name is for specific information only and does not imply approval or recommendation of the company by USDA to the exclusion of others that may be suitable.

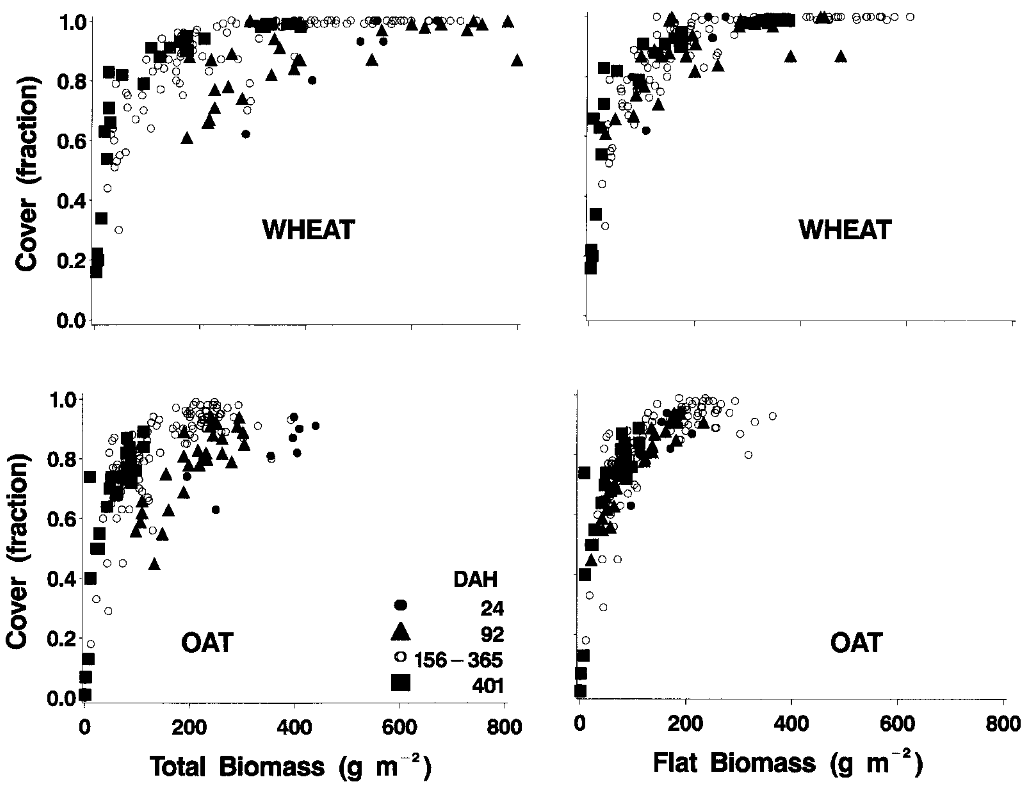

Fig. 1. Relationship between total and flat biomass for winter wheat and oat crops. Two prewinter sample dates (24 and 92 DAH), the final sample date (401 DAH), and all other sample dates combined, are identified.

application made the alternate-date application unnecessary). No irrigation was applied when daily mean air temperature was at or below freezing.

Residue biomass samples were collected from controlled traffic areas of the plots and processed seven times in 14 mo as described in Steiner et al. (1999). Briefly, standing residues (>10° from horizontal) were collected and processed separately from flat surface residues. Standing residues were washed to remove soil, if needed. All samples were dried at 60°C and weighed. Surface residue samples were ground to pass a 0.635-mm screen and subsamples were weighed, ashed in a muffle furnace at 500°C for 4 h, and weighed to determine the soil fraction of the sample. Residue mass for the surface samples were corrected to ash-free mass and summed with standing-stem biomass obtain total biomass. Initial biomass and cover measurements were made in July 1991 (24 d after harvest, DAH) and continued until August, 1992 (401 DAH). Harvest of all crops occurred over about a 3 wk period in June 1991 during an extremely hot, dry period. Though the actual days from harvest was different for different crops and plots, residues had not undergone decomposition on any plot and the decomposition time was treated as the same for all plots.

Prior to obtaining each destructive biomass sample, a nadir view photograph was taken of the 1-m^2 area to be sampled, similar to the method reported by Molloy and Moran (1991). The ends of the 1.0-m plots were marked with white plastic pipe, perpendicular to the rows. A 35-mm camera was supported at 3.5 m above the plot on a boom. Photographs were taken with Kodachrome 64 ASA slide film, an aperture setting of F8 or F11, and the camera shutter speed set on automatic control. A zoom lens was set at 70-mm focal length. A shutter release cable was used to take the picture after the camera was in position. Photographs were taken 1 d and biomass sampling required multiple days, depending on the degree of residue decomposition and number of available workers.

Contrast between soil and residue was poor, particularly when the soil was dry and/or the residues were aged. The best contrast was obtained when skies were overcast. On clear days, the photographs were taken near solar noon to minimize shadows. McCool et al. (1989) used shades to reduce shadows in photographs taken for cover estimates. Because of the low and variable contrast between soil and residue, manual counting (description follows) was determined to be the most reliable method of determining residue cover as compared with image analysis.

Residue cover of each plot was measured by projecting the slide onto a screen for counting. To prepare a screen for counting, a rectangle proportional to the sample site dimensions was drawn on stiff, smooth matte board. (Although the soil area sampled was square, projection of the area was rectangular.) Marks were randomly placed at 1- to 10-cm intervals along the perimeter of the rectangle and lines were drawn at 45° angles to the perimeter line from each mark. Lines drawn from the upper and right side of the rectangle were perpendicular to the lines drawn from the lower and left sides. A 3-mm circle was drawn on the screen at each intersection, with a total of 163 points, consistent with recommendations of Morrison et al. (1989). Our procedure provided randomly located dots to avoid bias associated with rows in determining cover, but the diagonal lines could be traced visually to ensure that all dots were counted only once.

To determine residue cover, a slide was projected onto the screen and adjusted so the 1.0-m^2 sample area was projected within the rectangle. Each of the 163 dots were examined to determine if soil or residue projected onto the dot. For plots with high residue cover, residue *misses* were counted with a hand-held inventory counter. For plots with low residue cover,

Table 1. Biomass:cover coefficients for total above ground biomass (k_t) and flat biomass (k_f) fit by crop across all sampling dates and by days after harvest (DAH), standing fraction (standing biomass:total biomass), number of standing stems, and stem mass (standing biomass/stem number) for each crop:date combination.

Crop	DAH	*n*†	k_t	k_f	Standing fraction‡	Standing stems‡	Stem mass‡
			m^{-2} g^{-1}		g^{-1} g^{-1}	# m^{-2}	g $stem^{-1}$
Barley	All dates	188	0.0151	0.0172			
	24	27	0.0059	0.0117	0.46 (0.11)	581 (257)	0.34 (0.09)
	92	27	0.0098	0.0187	0.39 (0.15)	376 (194)	0.29 (0.10)
	156	27	0.0100	0.0125	0.16 (0.11)	164 (115)	0.25 (0.14)
	224	27	0.0206	0.0229	0.14 (0.15)	138 (133)	0.20 (0.11)
	301	26	0.0151	0.0154	0.04 (0.06)	34 (83)	0.20 (0.21)
	365	27	0.0203	0.0219	0.02 (0.03)	15 (26)	0.04 (0.05)
	401	27	0.0194	0.0196	0.01 (0.01)	5 (9)	0.03 (0.06)
Oat	All dates	189	0.0162	0.0180			
	24	27	0.0055	0.0137	0.56 (0.06)	485 (128)	0.37 (0.09)
	92	27	0.0077	0.0165	0.41 (0.15)	274 (110)	0.31 (0.18)
	156	27	0.0124	0.0157	0.09 (0.12)	55 (73)	0.18 (0.31)
	224	27	0.0173	0.0191	0.04 (0.07)	30 (48)	0.09 (0.17)
	301	27	0.0165	0.0171	0.01 (0.02)	6 (10)	0.08 (0.22)
	365	27	0.0194	0.0198	0.01 (0.03)	6 (14)	<0.01 (0.01)
	401	27	0.0228	0.0229	<0.01 (0.01)	<1 (1)	0.01 (0.03)
Spring wheat	All dates	187	0.0099	0.0171			
	24	27	0.0026	0.0183	0.69 (0.14)	359 (93)	0.44 (0.10)
	92	27	0.0049	0.0196	0.66 (0.11)	302 (94)	0.45 (0.10)
	156	26	0.0064	0.0119	0.36 (0.19)	157 (95)	0.48 (0.15)
	224	27	0.0139	0.0206	0.32 (0.18)	129 (107)	0.47 (0.13)
	301	26	0.0127	0.0166	0.22 (0.14)	75 (79)	0.34 (0.12)
	365	27	0.0138	0.0171	0.14 (0.13)	49 (60)	0.27 (0.10)
	401	27	0.0141	0.0162	0.08 (0.08)	33 (44)	0.19 (0.15)
Winter wheat	All dates	184	0.0192	0.0197			
	24	24	0.0045	0.0138	0.59 (0.07)	832 (165)	0.34 (0.08)
	92	27	0.0064	0.0167	0.45 (0.17)	525 (197)	0.31 (0.13)
	156	25	0.0113	0.0147	0.21 (0.21)	155 (156)	0.37 (0.21)
	224	27	0.0283	0.0267	0.12 (0.12)	128 (141)	0.27 (0.11)
	301	27	0.0153	0.0168	0.05 (0.06)	46 (46)	0.19 (0.13)
	365	27	0.0196	0.0213	0.06 (0.15)	51 (104)	0.11 (0.12)
	401	27	0.0420	0.0490	0.04 (0.15)	15 (31)	0.10 (0.12)

† Initial Density, Irrigation, and Replications were combined to obtain adequate range of values to allow convergence of the solution.
‡ Mean (standard deviation) across Density, Irrigation, and Replicate values.

residue *hits* were counted. Fraction cover was calculated by dividing the number of hits by 163.

Calculating Biomass-to-Cover Coefficients

The exponential relation between cover and biomass developed by Gregory (1982) was fit to determine the cover coefficient for each crop on each date.

$$\text{Cover} = [1 - \exp^{-k(M)}]$$

where M is residue biomass (g m^{-2}), and k is a cover coefficient (m^2 g^{-1}) and cover is the fraction of soil covered.

Statistical Analysis

Cover coefficients were determined for each crop-sample date combination with total biomass used to calculate k_t or flat biomass to calculate k_f by the MODEL procedure of SAS (1988). For each sample date and crop, data were pooled across density and irrigation treatments to obtain a range of biomass and cover values. We determined relationships of k_t and k_f to DAH using the GLM procedure (SAS, 1989) and analyzed for heterogeneity of slopes for different crops using the procedure described by Freund et al. (1986) for solving linear models within the GLM procedure.

RESULTS AND DISCUSSION

The biomass relationship to soil cover is shown for all sample dates for winter wheat and oat (Fig. 1). Spring wheat and barley data produced similar results as wheat and oat (data not shown). As Fig. 1 shows, data collected prior to winter (24 and 92 DAH) tended to produce less soil cover per unit biomass than samples collected later. This is logical because of the large fraction of standing biomass that produced relatively little soil cover (Table 1), and because little soluble material would have leached from the residues prior to the initial sampling on 24 DAH. For flat biomass, the relationship of biomass to cover changed less over time than with total biomass.

The k_f and k_t values and properties of the standing stems for each crop-date combination are summarized in Table 1. The coefficients tended to increase as decomposition progressed, particularly for k_t. As the standing stem number and fraction of total biomass that was standing decreased, the k_t and k_f values converged. The decrease in mass per unit stem over time (Table 1) could be related to leaching of soluble materials, decomposition of leaf sheath material, and breakage of the stems.

The relative effectiveness of the biomass of different small grain species in providing soil cover remains unclear when comparing our results to other reports in the literature. Our experiment showed that across the decomposition period, winter wheat provided the most and spring wheat the least cover per unit biomass, differing from the results of Greb (1967) and McCool et al. (1990). Our data indicate that oat provided an average amount of cover compared to other small grain residues, in contrast to the findings of Sloneker and Moldenhauer (1977) that oat provided exceptionally high cover per unit biomass (0.014 m^2 g^{-1}). For fresh residues (24 DAH), our k_t values were 0.0026 for spring wheat,

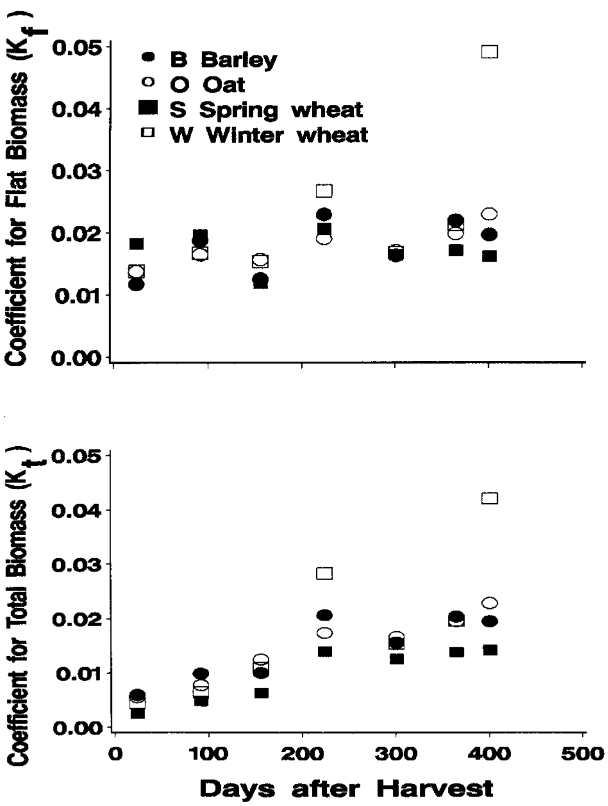

Fig. 2. Change in the biomass to cover coefficients for total biomass (k_t) and flat biomass (k_f) over time.

0.0045 for winter wheat, 0.0055 for oat, and 0.0059 for barley. The average k_t across crops on 24 DAH, 0.0046 $m^2\ g^{-1}$, is similar to the average of values reported for small grains by Gregory (1982) of 0.0055 $m^2\ g^{-1}$ [0.0049 $m^2\ g^{-1}$ without the value for oat from Sloneker and Moldenhauer, (1977)], and 0.0057 $m^2\ g^{-1}$ reported by McCool et al. (1990) for freshly harvested stem residues from small grain species and cultivars in northwestern USA. Our biomass data included all residue, including fine material such as small leaf fragments and awns.

Our k_t values diverged from published values at later sampling dates when residue elements were leached and highly decomposed. The time trend in the coefficients for each crop is shown graphically in Fig. 2. The k_t values increased over time, indicating that residue cover decreased more slowly than residue biomass. For both total and flat biomass relationships, winter wheat on 401 DAH provided over 0.8 fraction cover with less than 50 g m^{-2} biomass (Fig. 1), indicating that residue elements maintained integrity and provided soil cover when the residue had decomposed to very low levels.

To determine if the trend of increasing coefficient values over time was significant, we fit a linear regression of k_f and k_t on DAH for each crop (Table 2 and Table 3). Preliminary analyses indicated that there were no significant differences in intercepts for the relationships among crops (data not shown), so the relationships were fit with the restriction that they have a common intercept to compare the slopes. For all crops, k_t increased with time ($P < 0.0001$, except for spring wheat at $P < 0.0041$). Slopes for barley ($P < 0.03$), oat ($P <$ 0.05), and spring wheat ($P < 0.0005$) were lower than the slope for winter wheat (data not shown). When analyzed across the four small grain crops, the relationship was $k_t = 0.0037 + 0.000047 \cdot \text{DAH}$ ($r^2 = 0.54$, $P <$ 0.0001), which provides an estimated k_t ranging from 0.004 $m^2\ g^{-1}$ at 0 DAH to 0.023 $m^2\ g^{-1}$ at 400 DAH, almost an order of magnitude change during the decomposition period. This relationship indicates that decomposition effects should be considered when applying total biomass-cover relationships through extended decomposition periods.

Table 2. Test of the heterogeneity of slopes across crops for the linear regression of total biomass:cover coefficient(k_t) on days after harvest (DAH). Equation tested: $k = a + b$(DAH).

Parameter	Estimate of parameter	t	$P > t$	SEE†
Intercept‡	0.003762	2.17	0.0405	0.00173
Slope: Barley	0.000045	5.06	0.0001	0.00001
Slope: Oat	0.000047	5.28	0.0001	0.00001
Slope: Spring Wheat	0.000028	3.19	0.0041	0.00001
Slope: Winter Wheat	0.000067	7.56	0.0001	0.00001

† Standard error of the estimate.
‡ The unrestricted analysis indicated that the intercepts for barley, oat, and spring wheat were not different from the intercept for winter wheat at $P = 0.35$, 0.51, and 0.84, respectively, so the relationships were analyzed with the restriction that all equations have the same intercept.

For flat biomass (Table 3), winter wheat k_f was most strongly related to time ($P < 0.0003$), and spring wheat appeared to be little affected by time ($P < 0.3$). Slopes for barley ($P < 0.11$) and oat (0.09) were marginally significant, and lower than the slope for winter wheat ($P < 0.03$). Analysis without the data point for 401 DAH for winter wheat resulted in a higher intercept (0.014873) and lower slopes that were not significantly different across crops. When analyzed across the four small grain crops, the relationship was $k_f = 0.0136 + 0.000023 \cdot \text{DAH}$ ($r^2 = 0.17$, $P < 0.017$), providing estimated k_t values ranging from 0.015 $m^2\ g^{-1}$ on 0 DAH to 0.020 $m^2\ g^{-1}$ at 400 DAH. This weak relationship indicates that a single coefficient between flat biomass and soil cover (about $k_f = 0.0175$) could be used through extended decomposition periods with reasonable accuracy.

CONCLUSIONS

Frequently, soil cover is estimated from total biomass for use in erosion estimation and other applications. Our data showed that in no-tillage conditions, the rela-

Table 3. Test of the heterogeneity of slopes across crops for the linear regression of flat biomass:cover coefficient(k_f) on days after harvest (DAH). Equation tested: $k = a + b$(DAH).

Parameter	Estimate of parameter	t	$P > t$	SEE†
Intercept‡	0.013600	6.56	0.0001	0.00207
Slope: Barley	0.000018	1.67	0.1079	0.00001
Slope: Oat	0.000019	1.78	0.0883	0.00001
Slope: Spring Wheat	0.000011	1.05	0.3057	0.00001
Slope: Winter Wheat	0.000046	4.29	0.0003	0.00001

† Standard error of the estimate.
‡ The unrestricted analysis indicated that the intercepts for barley, oat, and spring wheat were not different from the intercept for winter wheat at $P = 0.50$, 0.49, and 0.17, respectively, so the relationships were analyzed with the restriction that all equations have the same intercept.

tionship between total biomass and cover changed significantly as the residues decompose. After harvest, a high proportion of total biomass is standing stems that provide relatively little cover. On a seasonal basis, contribution of the standing biomass to cover is important, because the stems provide soil cover as they fall later in the decomposition season. The relationship between flat biomass and cover was relatively stable over time and our results indicate that the same coefficient could be used through the season with relatively little error.

There is a range of values for cover coefficients for different small grains in this study (k_t and k_f) and in the literature (k_t). There is no consistent trend showing which small grain species is most efficient in providing cover, although data from Sloneker and Moldenhauer (1977) for oat (0.014 $m^2\ g^{-1}$) and our winter wheat data (0.042 $m^2\ g^{-1}$ on 401 DAH) indicate that an exceptional amount of cover can be provided with a small amount of decomposed small grain residue. Genotype, climate, and other agronomic conditions appear to affect the coefficient value as well as species. Use of an average 0.005 $m^2\ g^{-1}$ taken from published values of for freshly harvested small grains appears warranted at this time, unless a coefficient value can be measured for a specific application. However, our data indicate that it would be better to estimate soil cover on the basis of flat residue biomass rather than total residue biomass by means of an average of $k_f = 0.0175\ m^2\ g^{-1}$. Alternatively, a value for k_f varying from 0.015 $m^2\ g^{-1}$ for freshly harvested residue to 0.02 $m^2\ g^{-1}$ for highly decomposed residue could be used. If total residue biomass is used to estimate cover over extended periods of time, the k_t will vary considerably, from 0.004 $m^2\ g^{-1}$ for fresh residues to 0.023 $m^2\ g^{-1}$ for highly decomposed residues.

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